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Implementation of Spectral Maxima Sound processing for cochlear implants by using Bark scale Frequency band partition

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Abstract **A new method on the basis of Bark scale frequency-band partition was presented to improve the recognition performance of cochlear implants. In the nature of physics, it consists with human's cochlea filter properties. Also the mechanism of a cochlear implant and its spectral maxima sound processing (SMSP) strategy were presented. The time-frequency analyzing property of human's cochlea was analyzed.**

The theoretical determination of Bark scale frequency-band was also given with formula. Simulation results using Bark scale transform signal processing were discussed in detail and results show that the new method is feasible in speech processors for cochlear implants.

Key words **cochlear implant, Bark scale, SMSP strategy, speech signal processing**

I. INTRODUCTION

Cochlear Implant is a hearing device restoring hearing ability to the deaf with electricity stimulation. It mainly acts as imitating the physiological function of peripheral acoustical nerve such as outer, middle and inner ear of normal people. The nucleus of surrounding acoustical system is cochlea in inner ear. Cochlea is a snail-shaped organ that translates sound energy into nerve impulses and then sends them to the brain for processing. Sound is transmitted in the form of traveling wave, so cochlea can be taken as theoretically that it is composed of a group of space-distributed band-filters, and the same long basilar membrane (about 1.5mm) in cochlea is equivalent to a filter of same bandwidth called Bark scale domain [1,2]. Multi-channel cochlear implant is designed based on cochlea's filtering properties for speech signal. Speech signal-processor deals with speech signal in segment band, and produces simulating signal of corresponding electrodes to excite different part acoustical nerves in cochlear.

SMSP strategy is one of signal processing algorithms that was developed in the early 1990s cochlear implant. It divides speech signal into sub-bands using 16 band filters, and then detects out envelope information of each band signal and selects 6 or 8 maxima spectral to produce electrical stimulation current. In SMSP algorithm, the bandwidth of filters usually is logarithm-law or octave-law relation. However, this frequency-band partition of filters is not completely consistent with the nature of physics which is inherent in human ear. So the speech recognition performance of SMSP strategy should be improved.

According to above analysis, this paper discusses the application of Bark scale transform in speech signal-processing of cochlear implants. We hope that the results would provide reference to the implementation of speech signal digital processing in cochlear implants, and at the same time, the relevant conclusion would be helpful for improving the speech recognizing ability of the deaf.

II SMSP STRATEGY

A The mechanism of cochleae implant

When sound signal transmits in the form of traveling wave in cochlea, the amplitude of its high frequency band is the strongest in cochlea's basal end, and the amplitude of its low frequency-band is the strongest in of cochlea's apical end. So the cochlea is a mechanical-frequency analyzer in the space.:

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The basal end of cochlea accepts high-frequency signal and the apical end accepts low-frequency signal. Acoustical frequency between the apical end and the basal end along the basilar membrane ranges from 16Hz to 20kHz。Physiological experiments give further evidence that the frequency-analyzing feature of cochlea is similar to that of the same bandwidth filters in Bark scale domain. The frequency bandwidth of each filter is approximately equal to the length of basilar membrane in cochlea which includes about 1200 pieces of nerve fiber.

Cochlear implant is the imitation of normal hearing man's cochlea. In artificial cochlea, a group of electrodes is implanted into cochlea's scala tympani along the basilar membrane. The speech processor outside of body produces electricity-stimulating signals corresponding as electrodes. The implanted circuit of generating stimulating-electricity current inner body produces stimulating-pulses. These pulses activate intact auditory nerves in cochlea. Then the exciting of auditory nerves near all electrodes is transmitted to speech center of pallium to induce hearing perceptual ability, and so restore primary language communication ability for the deaf.

B Spectral maxima sound processing strategy in cochlear implants

Unlike previous speech signal-processing algorithm developed for the Nucleus implant, SMSP strategy did not extract any features (e.g., F1, F2) from the speech waveform. Instead, it analyzed the speech signal a bank of 16 bandpass filters and a spectral maxima detector. Figure 1 shows the block

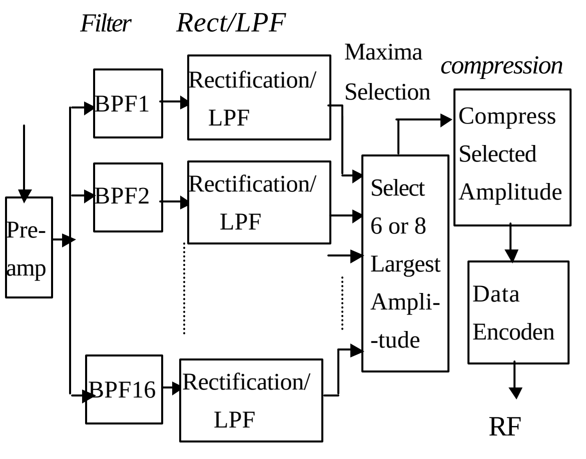


Figure1 The schematic of SMSP strategy

diagram of the SMSP strategy in cochlea implant. In SMSP strategy, signal from the microphone is firstly pre-amplified and then sent through a bank of 16 bandpass filters with center frequencies ranging from 200 to 5,000 Hz. The output of each filter is rectified and low-pass filtered with cutoff frequency of 200 Hz. After computing all 16 filter outputs, the SMSP strategy selects, at certain time intervals, 6 or 8 largest filter outputs. The 6 or 8 amplitudes are finally logarithmically compressed, to fit the patient's electrical dynamic range, and after being modulated by bipolar pulse-sequences transmitted to the 6 or 8 selctected electrodes through a radio-frequency link. The term "maxima" refers to the largest filter amplitudes, which are not necessarily the spectral peaks［3~5］.

Electrical stimulation pulsatile current in SMSP strategy would be gained according as the varied amplitude of selected sub-band signal. The number of electrodes is 16, but only 6 or 8 electrodes is selected to been stimulated [6]. In SMSP strategy, how frequency-band partition should be made is critical for gaining effective parameters of stimulating electrodes, consequently the optimal recognition performance can be obtained. The frequency-bandwidth of filters in figure 1 is usually octave-law relation or logarithm-law relation. These band filters can be implemented in the form of digital or analog filter. At present, the implementation of filtering in cochlea implant is based on digital filter.[7,8]. The band-pass filters with frequency-band partition of speech signal in Bark scale domain consist with human's cochlea filter properties. The stimulating pulses which are derived from envelopes can effectively represent ones produced by nerve fibers on the same long basilar membrane of cochlea. This paper develops a new speech signal-processing method in cochlea implant where frequency-band partition of band-pass filters is based on Bark scale transform.

III BARK SCALE TRANSFORM AND ITS IMPLEMENTATION IN SMSP STRATEGY

A Definition of Bark Scale transform

The function of basilar membrane is similar to frequency-spectra analyzer. We can separate frequency of speech signal ranging from 20 to

16,000Hz into 24 frequency groups (critical band), and this partition of frequency groups is consistent with division of basilar membrane into many same long small parts. Each small part of basilar membrane is corresponding to a frequency group. The sound of these frequency on the same segment of basilar membrane may be evaluated as a whole by adding them together. So we can say that the corresponding relation between perceptual frequency of auditory organ and actual frequency of sound signal is nonlinearly mapped. So the concept of Bark scale can be introduced. Traunmullar presented the function relation between linear frequency and Bark scale frequency, i.e.:

$$b=6.7\text{asinh}\left[(f - 20) / 600 \right]$$

$$\text{or} \quad b = 26.81f / (1960 + f)$$

Where b denotes Bark scale frequency, f is linear frequency. Their relation is showed in figure 2.

B the implementation of SMSP strategy with Bark scale transform

In the nature of physics, the frequency-band partition in Bark scale domain in SMSP strategy consists with human's cochlea filter properties. So the band division of Bark scale domain can replace the partition of logarithm-law or octave-law in band-pass filters of SMSP algorithm. In experiments, firstly signal from the microphone is pre-amplified and then sent through a bank of 16 bandpass filters with Bark scale transform. Secondly the output of each filter is all-wave rectified and low-pass filtered with cutoff frequency of 200 Hz. After computing all 16 filtering outputs, the SMSP strategy selects, at certain intervals, 6 or 8 largest filtering outputs. The cosine wave whose frequency is center frequency corresponding to selected band-pass filter modulates

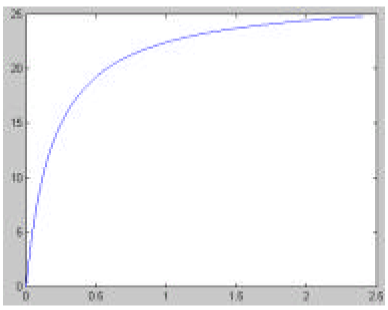


Figure2 The relation of Bark (clinical band) frequency band and linear frequency

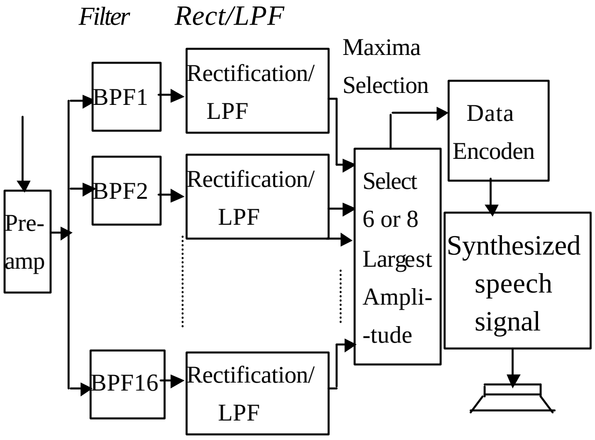


Figure 3 The schematic of SMSP strategy using Bark scale band transform

envelope signal. Finally the modulated signal after being added together directly drives loudhailer to sound. Figure 3 shows the block diagram of the SMSP strategy in this paper. In experiments, the performance of synthesized speech signal is estimated by normal people, so this algorithm takes no account of amplitude dynamic-range and omits compressing function.

In SMSP strategy, the number of electrodes is 16. However Bark scale domain can be divided into 24 frequency-groups(clinical band) between 20 and 16,000Hz, so it's necessary that a few clinical bands should be combined together as bandwidth of band-pass filter according to sampling frequency of speech signal.

In this paper, we carried out experiments on 6 or 8 selected channels of SMSP strategies with Bark scale transform, and the center frequencies of corresponding band-pass filters. Table 1 shows center frequency, serial number of Bark scale and frequency-band in SMSP strategy. The sampling frequency of speech signal is 11,025Hz。

Ⅳ RESULTS AND DISCUSSION

In our experiment, the input speech signal of "Time、Good" (Fs=11.025kHz, 8bit) is analyzed and processed with SMSP strategy using Bark scale transform, and then cosine signal whose frequency is the center frequency of corresponding selected band-pass filters modulates processed signal. Finally modulated signal is added to form synthesized speech signal. The frequency-cut of low-pass filter which

extracts envelope signal is 200Hz. Band-pass filters and low-pass demodulating filter are designed in the form of elliptical properties under Matlab environment. band-passed signal is all-wave rectified , i.e.: the negative amplitude value is reversed and the positive is not changed.

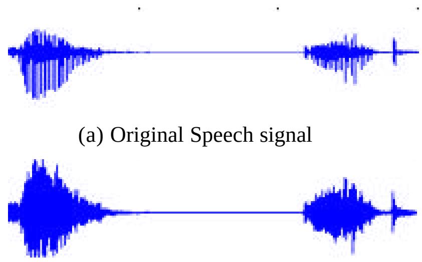
In experiment, the original speech signal of "Time and Good" was processed with 6 or 8 selected channels presented SMSP strategy and the experimental results were obtained. In this paper, we only displays simulating results of 8 selected channels SMSP strategy. Figure 4 (a) shows original wave of "Time and Good"，(b) shows synthesized speech wave processed with SMSP strategy. Figure 5 shows rectified envelope signal of 'Time" with 8 selected maxima spectral in certain interval filtered with 16 bandpass elliptical filters. The center frequency and bandwidth of all band-pass filters are showed in table 1.

We see from figure 4 that the synthesized speech signal using SMSP strategy with Bark scale transform basically is consistent with original signal. normal people can identify the sound which loudhailer utter with synthesized signal. In this signal-processing strategy, the combination of Bark scale serial numbers or a Bark scale forms

TABLE 1 The center frequency of bandpass filter in SMSP strategy and serial numbers of Bark scale domain

center frequ--ency（Hz）	Frequency range（Hz）	serial number of Bark scale domain
200	20—400	1—4
450	400—510	5
570	510—630	6
700	630—770	7
840	770—920	8
1000	920—1080	9
1170	1080—1270	10
1370	1270—1480	11
1600	1480—1720	12
1850	1720—2000	13
2150	2000—2320	14
2500	2320—2700	15
2900	2700—3150	16
3400	3150—3700	17
4000	3700—4400	18
5000	4400—5520	19

bandwidth of band-pass filters. Envelope information of different band is obtain by filtering speech signal, and synthesized signal basicallyrepresents original speech. At the same time, this paper present a new method of frequency-band partition for SMSP strategy, and the speech signal-processing in cochlea implant consists with the physiological nature of cochlea.



(a) Original Speech signal

(b) synthesized signal

figure 4 Original Speech signal and synthesized signal("Time and Good")

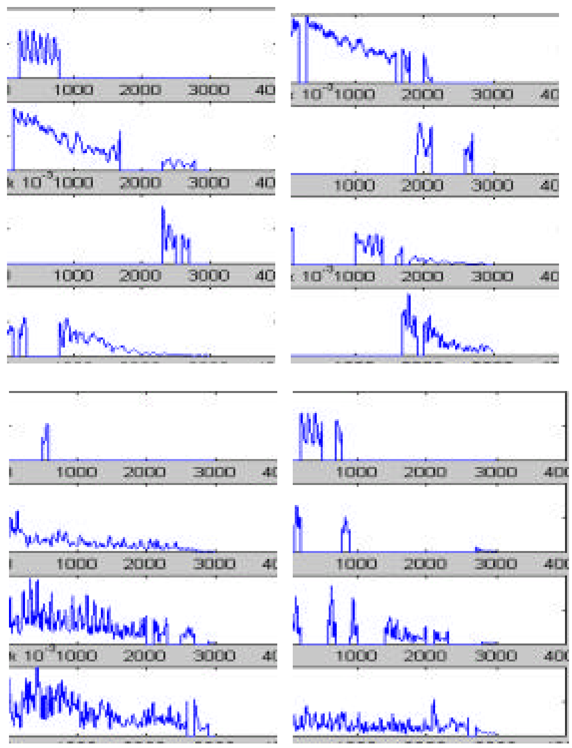


Figure 5 The processed 16 channels envelope signal of original speech "time"

Ⅴ CONCLUSION

This paper discusses the method of frequency-band partition in Bark scale domain is adopted in speech

signal-processing strategy of cochlea implant, and presents a new design scheme for cochlea implant. The experimental result shows that the frequency-band partition replacement of octave-law or logarithm-law in SMSP strategy with Bark scale domain is feasible. This frequency-band partition consists with human's cochlea filter properties. In this paper, we processed speech signal with SMSP strategy under Matlab. The compressing function for adjusting envelope amplitude is taken out. Envelope signal is directly modulated and then drives loudhailer to sound after added together. Results show that the sound which synthesized signal drive loudhailer to emit can be identified in principle by normal people.

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